Journal Pre-proof

Forecasting energy consumption of China's economic recovery post-covid-19 pandemic: Insights from energy sources and regional different

Qiang Wang, Fuyu Zhang, Rongrong Li, Lejia Li
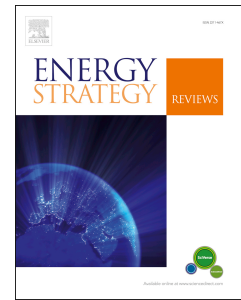
Please cite this article as: Q. Wang, F. Zhang, R. Li, L. Li, Forecasting energy consumption of China's economic recovery post-covid-19 pandemic: Insights from energy sources and regional different, *Energy Strategy Reviews* (2022), doi: https://doi.org/10.1016/j.esr.2022.100881.

This is a PDF file of an article that has undergone enhancements after acceptance, such as the addition of a cover page and metadata, and formatting for readability, but it is not yet the definitive version of record. This version will undergo additional copyediting, typesetting and review before it is published in its final form, but we are providing this version to give early visibility of the article. Please note that, during the production process, errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

Author Contribution Statement

Qiang Wang: Conceptualization, Methodology, Software, Data curation, Writing- Original draft preparation, Supervision, Writing- Reviewing and Editing. **Fuyu Zhang**: Methodology, Software, Data curation, Investigation Writing- Original draft, Writing- Reviewing and Editing. **Rongrong Li**: Conceptualization, Methodology, Software, Methodology, Data curation, Investigation Writing- Original draft, Writing- Reviewing. **Lejia Li,** Methodology, Software, Methodology, Data curation, Investigation.

Forecasting Energy Consumption of China's Economic Recovery post-Covid-19 Pandemic: Insights from Energy Sources and Regional Different

Qiang Wang [1,2,3*], Fuyu Zhang [1,2], Rongrong Li [1,2,3*], Lejia Li [1,3]

1. School of Economics and Management, China University of Petroleum (East China), Qingdao, 266580, People's Republic of China

2. Carbon Neutrality Research Center, College of Management, Guizhou University, Guiyang, Guizhou, 550025, People's Republic of China

3. Institute for Energy Economics and Policy, China University of Petroleum (East China), Qingdao, 266580, People's Republic of China

*Corresponding author: lirr@upc.edu.cn (Rongrong Li); wangqiang7@upc.edu.cn (Qiang Wang);

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

1 **Forecasting Energy Consumption of China's**

2 **Economic Recovery of post-Covid-19 Pandemic:**

3 **Insights from Energy Sources and Regional Different**

4

5 **Abstract**

6 As the first country to restart the economy after the COVID-19 pandemic, China's

7 fast-growing energy consumption has brought huge challenges to the energy system.

8 In this context, ensuring stable energy supply and sustainable economic development

9 requires accurate estimation energy consumption of China's economic recovery of

10 post-Covid-19 pandemic. To this end, this study uses multiple panel regression model

11 to explore the relationship between energy consumption and economic growth from

12 the perspective of energy sources (total energy, coal, oil, natural gas) and regional

13 difference. The data from 30 provinces in China from 2000 to 2017 were selected.

14 Our findings indicate that China economic growth has led to the largest increase for

15 oil consumption, followed by natural gas consumption, and finally coal consumption.

16 That is, China economic growth has led to the largest increase for oil consumption,

17 followed by natural gas consumption, and finally coal consumption. In addition, the

18 coefficients of economic growth between regional energy consumption equations with

19 different energy consumption levels are heterogeneous. Among them, energy

20 consumption growth in provinces with high energy consumption is most affected by

21 economic growth, followed by provinces with low energy consumption, and finally

22 provinces with middle energy consumption.

23

24 **Keywords**: Energy consumption; economic growth; China; regional differences;

25   panel data

26

1. Introduction

28   The Coronavirus disease 2019 (COVID-19) pandemic jeopardizes the safety of

29   public life [1-3]. Many countries have adopted measures such as lockdowns, travel

30   bans and social distancing to control the spread of the virus [4]. These measures have

31   halted the spread of the virus but have also resulted in heavy financial costs[5]. GDP

32   fell by 3-6% in most countries and by 15% in some service-oriented countries[6, 7].

33   Moreover, these measures also affect the energy sector. For example, closures of

34   offices, factories, bars, restaurants and theaters reduce energy consumption by an

35   average of 10% in some European countries[8]. Energy consumption in the early

36   stage of the epidemic is reduced by more than 1.5 million barrels per day. Oil

37   consumption, in particular, is as the lowest point in 30 year[9]. The lower oil

38   consumption leads to a drop in prices[10, 11], which makes the epidemic bring

39   unprecedented challenges to the energy industry.

40   As the first country to effectively control the epidemic, China takes the lead in

41   entering a period of economic recovery[12]. On February 3, 2020, the Chinese

42   government proposed policies to help various production enterprises resume work and

43   production. Consequently, rapid recovery in industrial production has led to a

44   substantial increase in energy consumption. In the first half of 2021, China's

45   electricity consumption, coal consumption and natural gas market demand increases

46   by 16.2%, 10.7% and 21.2% year-on-year, respectively [13]. In December 2020,

47   Zhejiang, Hunan, Jiangxi, and Inner Mongolia autonomous regions successively

48   issued notices of orderly electricity consumption or power curtailment to deal with the

49   shortage of electricity and coal. Among them, Zhejiang Province, which uses the most

50 electricity, has the most severe power cuts. Besides, some factories produce

51 alternatively at the request of the government. The combinations of power cut and

52 alternative production threaten small and medium-sized enterprises struggling to

53 survive after the epidemic and hinder the economic recovery to a certain extent.

54   The economic recovery following the lifting of China's COVID-19 lockdown has

55 led to short-term fluctuations in energy consumption. To ensure the balance of energy

56 supply and demand, it is necessary to accurately explore the energy consumption of

57 China's economic recovery of post-Covid-19 pandemic. The relationship between

58 economic growth and energy consumption has always been a research hotspot[14, 15].

59 In general, these two variables for countries with different economic structures relates

60 to different stages of economic development[16]. In particular, due to the different

61 levels of industrialization and urbanization in different provinces in China, the impact

62 of economic recovery on energy demand varies [17]. In addition, various energy

63 sources have their own demand elasticity, which lead to differences in consumption of

64 coal, oil, and natural gas[18]. In this regard, this study investigates the relationship of

65 economic growth and energy consumption from two perspectives: regional

66 differences and sources differences. The energy consumption of China's economic

67 recovery of post-Covid-19 pandemic was reflected through the historical relationship

68 between economic growth and energy consumption. The conclusions answer the

69 questions "Which regions of China will experience the greatest increase in energy

70 consumption demand?" and "For coal, oil and gas, which energy consumption is most

71 affected by economic growth?", which are of great importance for the development of

72 China's energy planning in the post-epidemic era.

73   The rest of the study is organized as follows: Section 2 describes the relevant

74 literature review; Section 3 shows the methods and data used in the calculations;

75   Section 4 shows the empirical results and analyses; Section 5 provides an in-depth

76   discussion of the results; Section 6 gives conclusions and policy implications.

77

78   **2. Literature review**

79   Existing research has deeply explored the relationship between economic growth

80   and energy consumption from multiple perspectives through different methods [19-

81   21]. The conclusions in this field can be attributed to four hypotheses [22, 23]: The

82   first is the feedback hypothesis that economic growth and energy consumption are

83   causal to each other [24]；The second is to support the conservative hypothesis that

84   economic growth promotes energy consumption in one direction [25]；The third is

85   the growth hypothesis that energy consumption promotes economic growth in a single

86   direction [26, 27]；The fourth is the neutral hypothesis that there is no causal

87   relationship between economic growth and energy consumption [28]. Due to the

88   differences in the research objects and periods, the relationship between the two has

89   not yet reached a consensus [29]. Below we conduct a literature review from two

90   perspectives.

91   **2.1 Based on the regional perspective**

92   From the perspective of measurement model, studies can be divided into two

93   categories: time series data and panel data [30]. The research object of time series

94   data is mainly a single region. Taking India as an example, this study used the Engel-

95   Granger cointegration method to test data from 1950 to 1996 and found that there is a

96   two-way causal relationship between energy consumption and economic growth [31].

97   For Turkey, income is determined by energy consumption and foreign trade [32].

98   Dividing renewable and non-renewable energy consumption, this study focuses on the

99   time-varying causal relationship between energy consumption in the US energy sector

100 and actual GDP. The results of the time-varying causality technique show that all

101 departments have detected causality in different time periods [33]. There are also

102 some studies that focus on cities. Taking Anhui Province as an example, Ge et al.

103 found that GDP is a positive factor affecting electricity consumption through a

104 multivariate regression model [34]. In addition, the interaction mechanism between

105 energy consumption and economic growth in the Yangtze River Delta of China has

106 been investigated. Evidence shows that coal consumption has played a positive role in

107 accelerating economic development [35]. From the perspective of panel data, research

108 is usually carried out on a global or national scale. At the international level,

109 PerrySadorsky's results show that for 18 emerging economies including China,

110 economic growth has created opportunities for the growth of renewable energy

111 consumption in these countries [36]. On the contrary, a study of 27 EU countries did

112 not find a causal relationship between economic growth and energy consumption [37].

113 For 11 major industrialized countries at the same level of development, the results

114 show that, except for the case of Britain, Germany and Sweden, there is a neutral

115 hypothesis among the remaining countries. Besides, Canada, Belgium, the

116 Netherlands, and Switzerland have a one-way causal relationship from energy

117 consumption to GDP [38]. In the panel vector error correction model of six Central

118 American countries, the results show that there is a two-way causal relationship

119 between energy consumption and actual output [39]. At the national level, this study

120 based on 29 provinces in China found that energy consumption is the Granger cause

121 of GDP and financial development is not the Granger cause of GDP [40]. Panel data

122 models have been established in 50 states in the United States to study the complex

123 and controversial relationship between energy consumption and GDP. The results of

124 the Dumitrescu-Hering causality test indicate that there is mixed evidence for the

125   direction of the causal relationship between energy consumption and GDP in the short

126   term [41]. In short, different regions support different conclusions regarding the

127   impact of economic growth on energy consumption. Therefore, the following research

128   must fully consider the regional heterogeneity between regions.

129   **2.2 Based on the energy sources perspective**

130   With the deepening of study, energy consumption is divided into different sub-

131   energy sources. As the main primary energy source, coal has attracted many scholars

132   to investigate it. A study confirms that coal consumption may make a positive

133   contribution to economic growth through the autoregressive distribution lag limit test

134   method, which is called the growth hypothesis [42]. In this case, economic

135   development can easily become dependent on coal energy, especially in developing

136   countries. The energy-saving hypothesis supports that there may be a one-way

137   Granger causality from economic growth to coal consumption [43]. Moreover, some

138   studies provide support for the two-way causality between coal consumption and

139   economic growth [44]. The empirical results of OECD countries prove the neutral

140   hypothesis that a causal relationship cannot be established between coal consumption

141   and economic growth [45]. Oil is the world's main commercial energy source and acts

142   as an engine in economic development [46]. In addition to coal, Zheng et al.

143   thoroughly explored the relationship between China's industrial structure and their

144   respective oil consumption growth paths. The results suggest that the long-term

145   elasticity between oil consumption and the output value of the tertiary industry is the

146   largest, followed by the secondary industry. The output value of the primary industry

147   has a negative impact on oil consumption [47]. Zou et al. investigated the equilibrium

148   relationship between China's oil consumption and economic growth. The

149   cointegration test shows that these two variables tend to move together in the long run.

150   Furthermore, the Granger causality test indicates that oil consumption may be a useful

151   factor for predicting short-term and long-term economic changes. [48]. This may be

152   because the massive consumption of oil in industries and other fields may directly

153   promote the economy. In the four emerging economies of Russia, China, South Korea

154   and India, three-quarters of the countries have feedback effects between oil

155   consumption and economic growth. The results of Johansen's cointegration indicate

156   that rising oil prices have an adverse effect on the growth of emerging economies [49].

157   In China's "13th Five-Year Plan", natural gas has been listed as a vigorously

158   developed energy due to its low carbon emissions. Corresponding study has also

159   increased. Li et al. found a positive correlation between China's natural gas

160   consumption and economic growth, which means that promoting natural gas

161   consumption can improve the economy [50]. The work of Zheng et al. also reached

162   the same conclusion [47]. When Germany and Japan are undergoing major energy

163   reforms, natural gas consumption accounts for an increasing share of their energy

164   supply. The empirical results show that there is a two-way causal relationship

165   between these variables in Germany and Japan, which is consistent with the "feedback

166   hypothesis". The study of Magazzino et al. claims that the supply of natural gas

167   should be further strengthened to gradually replace the most polluting fuels (oil and

168   coal), ensuring a viable transition to the path to renewable energy [51]. In conclusion,

169   although the economy and energy have a close relationship, due to the differences in

170   the characteristics of energy, the consumption of various energy sub-types plays

171   specific roles in economic growth. Therefore, there are differences in the dependence

172   of economic growth on various energy sources, which is very important in the study

173   of energy economics.

174   To advance research on this issue, this study focuses on the energy sources and

175   regional different of energy consumption affected by economic growth. Regional

176   difference is examined by re-dividing 30 provinces into three regions (high energy

177   consumption region, medium energy consumption region, and low energy

178   consumption region) according to the level of energy consumption; Energy sources

179   difference is achieved by subdividing the total energy consumption into coal, oil, and

180   natural gas energy consumption. To this end, regional model and source model for

181   energy consumption were constructed, and the relationship between multiple energy

182   consumption and economic growth in 30 provinces in China was analyzed. In

183   addition, the impact of industrial structure and trade openness on energy consumption

184   is also included in the model. Conclusions are particularly important for China to

185   ensure energy security during the economic recovery period in the post-epidemic era.

186

187   **3. Data description and model construction**

188   **3.1 Variable selection and data description**

189   This study uses data samples from 30 provinces (including provinces, districts

190   and municipalities directly under the Central Government, hereinafter collectively

191   referred to as provinces) in China from 2000 to 2017 (excluding Tibet, Hong Kong,

192   Macao, and Taiwan). According to the 2017 energy consumption statistics of various

193   regions in the China Energy Yearbook, ten provinces with total energy consumption

194   higher than 190 million tons of standard coal are called high energy consumption

195   region (Guangdong, Hebei, Henan, Jiangsu, Liaoning, Inner Mongolia, Shandong,

196   Shanxi, Sichuan, Zhejiang). Ten provinces with total energy consumption between

197   100-190 million tons of standard coal are called middle energy consumption region

198   (Anhui, Fujian, Guangxi, Guizhou, Heilongjiang, Hunan, Shaanxi, Shanghai, Xinjiang,

199   Yunnan). Ten provinces with total energy consumption less than 100 million tons of

200   standard coal are called low energy consumption regions (Hainan, Qinghai, Hubei,

201   Ningxia, Beijing, Gansu, Tianjin, Jilin, Jiangxi, Chongqing) (as shown in Figure 1).

202
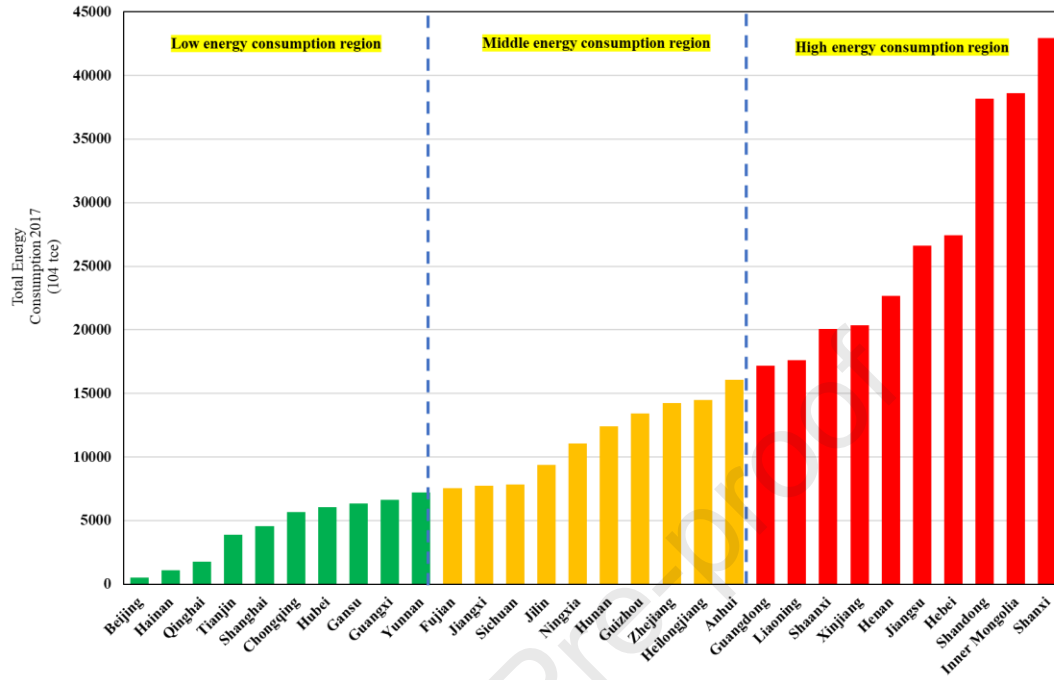
203   Figure 1. The division of energy consumption levels in China's 30 provinces.

204   The study selected variables such as total energy consumption, coal consumption,

205   oil consumption, natural gas consumption, economic growth, industrial structure, and

206   regional openness to construct an energy consumption function to explore the impact

207   of economic growth on energy consumption. The construction of each variable

208   selection is explained as follows. The relevant data comes from the "China Statistical

209   Yearbook", "China Energy Statistical Yearbook" and the provincial statistical

210   yearbooks over the years:

211   (1) The explained variable

212   Total energy consumption (TEC): Total energy consumption measures the level

213   of energy consumption. Total energy consumption refers to the sum of various energy

214   consumed by various industries and households in the national economy, and is

215   divided into three parts, namely, terminal energy consumption, energy processing and

216 conversion losses, and losses. To further investigate the difference of the impact of

217 economic recovery on the consumption of different types of energy, the annual

218 consumption of coal (COAL), oil (OIL), and natural gas (GAS) in each province was

219 selected and used as the regression equation of the difference test stage. Explanatory

220 variables.

221   (2) Core explanatory variables

222   Economic growth (GDP): Energy demand is linked to economic growth. To

223 ensure the balance of energy supply and demand during the economic recovery period,

224 it is necessary to quantitatively analyze the relationship between the two. This study

225 uses the GDP of each province to measure the level of economic growth. Regional

226 GDP can measure the economic conditions of the entire region and is a

227 comprehensive indicator of economic performance. In this study, the price of each

228 province in 1978 was used as the base price, and the price index was used to eliminate

229 the impact of price level changes.

230   (3) Other control variables

231   Industrial Structure (IS): As different industries have specific demands for

232 energy, structural changes are one of the factors that affect energy consumption. This

233 study reflects the industrial structure based on the proportion of the output value of

234 the secondary industry in each province in China in the total output value. The

235 secondary industry includes mining, manufacturing, electricity, heat, gas and water

236 production and supply, and construction.

237   Regional openness (OPEN): There is no consensus on the impact of foreign trade

238 on energy consumption in academia. On the one hand, regional openness has led to

239 the expansion of energy consumption. On the other hand, technological progress

240 brought about by trade opening may improve energy efficiency. This study reflects

241   the degree of regional openness based on the total import and export volume of each

242   province in my country (by domestic destination and source of goods).

243   To reduce the errors caused by heteroscedasticity and autocorrelation and avoid

244   spurious regression, each variable is in logarithmic form. The descriptive statistics of

245   the variables are shown in Table 1.

246   Table 1. Statistical description of variables

Variable	Description	Unit	Mean	Standard Deviation	Maximum	Minimum
TEC	Total energy consumption	10,000 tons of standard coal	11058.1651	7839.3337	38899	480
COAL	Coal consumption	Ten thousand tons	10918.9578	9007.9454	42942.29	192
OIL	Oil consumption	Ten thousand tons	1401.5720	1341.4886	7000.91	0.01
GAS	Natural gas consumption	One hundred million cubic meters	37.1180	39.8312	237.69	0.01
GDP	Economic Growth	100 million yuan	2329.5138	2326.7408	14376.2714	60.7558
IS	Industrial structure	%	0.4423	0.0787	0.5932	0.1901
OPEN	Regional openness	Ten thousand U.S. dollars	802.0532	1725.3177	12812	1.6069

247

248   **3.2 Measurement model**

249   To quantitatively analyze the impact of China's economic growth on energy

250   consumption, this paper introduces panel data to build a model, as shown in Eq (1):

$$lnTEC_{nt} = \alpha_1 lnGDP_{nt} + \beta X_{nt} + \delta_n + \varepsilon_t + \mu_{nt} \qquad (1)$$

251   Among them, n represents the cross-sectional unit of provinces, and the

252   benchmark model includes 30 provinces in China n=1, 2, …, 30; t represents time,

253   t=2000, 2001, …, 2017; $lnTEC_{nt}$ represents the logarithm of the total energy

254   consumption; $lnGDP_{nt}$ represents the logarithm of the GDP of each province,

255   reflecting the economic growth of each province; ε_t represents the time

256   non−observation effect, which reflects the influence of time−varying factors other

257   than the main variable, such as changes in policy and technology. δ_n represents the

258   regional non−observation effect, which reflects the persistent differences between

259   provinces, such as different carbon emission patterns, differences in regulations, and

260   differences in preferences due to differences in resource endowments. μ_{nt} is a random

261   error term that has nothing to do with time and region. X_{nt} is other control variables,

262   including industrial structure, regional openness, etc. Equation (1) is a benchmark

263   econometric regression model. To deeply explore the specific impact of economic

264   growth on various subdivisions of energy, total coal consumption, coal consumption

265    $lnCOAL_{nt}$, oil consumption $lnOIL_{nt}$, natural gas consumption $lnGAS_{nt}$ are

266   respectively regressed as explained variables.

267   **3.3 Estimation techniques**

268   First, we use the panel unit root test to test the stability of each variable. Second,

269   we use the panel cointegration test to determine the long-term cointegration

270   relationship between variables. Next, the fixed-effect OLS and FMOLS cointegration

271   estimates are used to analyze the long-term cointegration relationship between

272   variables.

273   **3.3.1 cross-sectional dependency (CSD) tests**

274   To solve the cross-sectional dependency problem, we choose the Breusch-Pagan

275   LM test proposed by [52], the Pesaran scaled LM test and the Pesaran CD test

276   proposed by [53] to check the data cross-sectional dependence. Among them, the test

277   of[52] is more suitable for small sample panels, and the formula is as Eq (2):

$$\text{LM} = \sum_{n}^{B-1} \sum_{m=n+1}^{B} A_{nm}\, \hat{\beta}_{nm}^2 \to x^2 \frac{B(B-1)}{2} \tag{2}$$

278   Pesaran scaled LM test is suitable for large samples, and the formula is as Eq (3)

$$LM = \sqrt{\frac{1}{B(B-1)}} \sum_{n}^{B-1} \sum_{m=n+1}^{B} (A_{nm} \hat{\beta}_{nm}^2 - 1) \rightarrow B(0,1) \tag{3}$$

279   A and B respectively represent the time dimension and the cross-sectional

280   dimension. In this study, A=18 and B=30. $\hat{\beta}_{nm}^2$ is the error-related parameter. The LM

281   test is based on the average of the residuals over the squares of the relevant

282   parameters of the sample. The null hypothesis of the test is as follows: $H_0: \hat{\beta}_{nm} =$

283   0,n≠m, which means that there is no cross-sectional correlation, $H_1: \hat{\beta}_{nm} \neq$ 0,n≠m，

284   which means that there is cross-sectional correlation. But when n→ ∞, the LM test

285   may fail. The CD test proposed in [53] solves this problem, and the formula is as Eq

286   (4):

$$CD = \sqrt{\frac{2}{B(B-1)}} \sum_{n=1}^{B-1} \sum_{m=n+1}^{B} A_{nm} \hat{\beta}_{nm}^2 \rightarrow B(0,1) \tag{4}$$

287   Among them,$\hat{\beta}_{nm}^2$ is the residual related statistics. A and B respectively represent the

288   time dimension and the cross-sectional dimension.

289   **3.3.2 Panel unit root tests**

290   The four unit root tests (LLC, IPS, Fisher-ADF and Fisher-PP) used in this study

291   include the same root test and the different root test. If the result shows that the null

292   hypothesis is accepted, that is to say, the null hypothesis exists, the variable is not

293   stationary, and the result rejects the null hypothesis, the variable is stable.

294   Among them, the formula of LLC test is as Eq (5)[54]：

$$\Delta Q_{ef} = a_e Y_{ef-1} + \sum_{L=1}^{mn} b_{ep} \Delta Y_{ef-L} + c_{pe} d_{pf} + e_{ef}, \ p = 1,2,3 \tag{5}$$

295   Where a_i 、 c_{pe} 、 d_{pf} 、 e_{ef} it represent the autoregression coefficients, the

296   corresponding vectors of the regression coefficients, and the corresponding vectors of

297   the regression parameters are p=1,2,3. The principle of IPS testing is similar to that of

298   LLC testing. [55]. Besides, The different root test Fisher-PP was developed by

299   Phillips and Perron. [56]The expressions are as Eq (6) and Eq (7):

$$\text{Fisher\_ADF} = -2\sum_{m}^{p}\log(Mq) \to \text{P} \tag{6}$$

$$\text{Choi\_ADF} = \frac{1}{\sqrt{T_{m-1}}}\sum_{m-1}^{K}\theta^{-1}(Mq) \to \text{K}(0,1) \tag{7}$$

300   Where m、 θ^{-1} denotes the reciprocal of the normal distribution function, Mq denotes

301   the P-value of the ADF unit root test. The null hypothesis is $a_i=0$ there is a unit root;

302   if $a_i<0$ there is no unit root.

303   **3.3.3 Panel cointegration tests**

304   In this study, the panel Pedroni test [57] and Kao test [58]are selected.

305   Cointegration test is used to investigate whether there is a cointegration relationship

306   between variables. Pedroni's cointegration test includes two important hypotheses:

307   panel statistical test and outlier statistical test. details as Eq (8)- Eq (12):

308   A.Panel-ρ

$$F\sqrt{PQ_{\hat{\rho}A,F-1}} \equiv \text{F}\sqrt{P}(\sum_{\alpha=1}^{P}\sum_{\beta=1}^{F}\hat{L}_{11\alpha}^{-2}\varepsilon_{\alpha,\beta-1}^{2})^{-1}\sum_{\alpha=1}^{P}\sum_{\beta=1}^{F}\hat{L}_{11\alpha}^{-2}(\hat{\varepsilon}_{\alpha,\beta-1}\Delta\hat{\varepsilon}_{\alpha,\beta} - \widehat{\theta_{\alpha}}) \tag{8}$$

309   B.Panel- β

$$Q_{\alpha P,F}^{*} \equiv (S_{P,F}^{*2}\sum_{\alpha=1}^{P}\sum_{\beta=1}^{F}\hat{L}_{11\alpha}^{-2}\varepsilon_{\alpha,\beta-1}^{2})^{-\frac{1}{2}}\sum_{\alpha=1}^{P}\sum_{\beta=1}^{F}\hat{L}_{11\alpha}^{-2}\varepsilon_{\alpha,\beta-1}\Delta\hat{\varepsilon}_{\alpha,\beta} \tag{9}$$

310   C. Group-ρ

$$F\tilde{Q}_{\tilde{\rho}A,F-1} \equiv FP^{-\frac{1}{2}}\sum_{\alpha=1}^{P}(\sum_{\beta=1}^{F}\varepsilon_{\alpha,\beta-1}^{2})^{-1}\sum_{\beta=1}^{F}(\hat{\varepsilon}_{\alpha,\beta-1}\Delta\hat{\varepsilon}_{\alpha,\beta} - \widehat{\theta_{\alpha}}) \tag{10}$$

311   D. Group- β

$$P^{-\frac{1}{2}}\tilde{Q}_{\tilde{\rho}P,F} \equiv P^{-\frac{1}{2}}\sum_{\alpha=1}^{P}(\sum_{\beta=1}^{F}S_{\alpha}^{*2}\varepsilon_{\alpha,\beta-1}^{2})^{-\frac{1}{2}}\sum_{\beta=1}^{F}\hat{\varepsilon}_{\alpha,\beta-1}\Delta\hat{\varepsilon}_{\alpha,\beta} \tag{11}$$

312 where

$$\widehat{\theta_{\alpha}} = \frac{1}{2}(\hat{\mu}_{\alpha}^{2} - \hat{s}_{\alpha}^{2}); s_{P,F}^{*2} = \frac{1}{P}\sum_{\alpha}^{P}s_{\alpha}^{*2} \tag{12}$$

313 **3.3.4 Panel cointegration estimates**

314   The cointegration test is followed by regression estimation. Ordinary Least

315 Squares (OLS) and Fully Modified Least Squares (FMOLS) are adopted. FMOLS is

316 widely used in regression [59]. Compared with OLS estimation, FMOLS estimation

317 can correct sequence correlation and prevent the occurrence of spurious regression. It

318 is a more effective panel econometric technique. The equation proposed by Pedroni is

319 as Eq (13) [60] :

$$Y_{mn} = l_{m} + mx_{mn} + \sum_{p=-P_{m}}^{P_{m}}\mu_{mp}\Delta x_{mn-p} + \theta_{mn} \tag{13}$$

320   Define $\rho_{mn} = (\hat{\theta}_{mn}, \Delta x_{mn})$、 $\delta_{mn} = \lim_{D\to\infty}E\left[\frac{1}{D(\sum_{d=1}^{D}\rho_{mn})(\sum_{d=1}^{D}\rho_{mn})}\right]$, δ_{mn} is the

321 long-term covariance. In this equation, x and Y_{mn} have a cointegration relationship.

322 The long-term covariance can be decomposed into $\delta_{m} = \delta_{m}^{o} = \omega_{m} = \omega_{m}'$, where δ_{m}^{o}

323 is the weighted sum of the covariance, ω_{m} is the automatic covariance and ω_{m} The

324 FMOLS criteria are as Eq (14):

$$\hat{\alpha}_{FMOLS} = \frac{1}{Q}\sum_{m}^{Q}\left[\frac{1}{(\sum_{d=1}^{D}x_{mn} - \bar{x}_{m})^{2}}(\sum_{d=1}^{D}(x_{mn} - \overline{x_{m}})y_{mn}^{*} - \omega_{\widehat{\mu_{m}}})\right] \tag{14}$$

325   Where $\quad y_{mn}^{*} = y_{mn} - \bar{y}_{m} - \left(\hat{\delta}_{2,1,m}\overline{\hat{\delta}}_{2,2,m}\right)\Delta x_{mn}, \hat{\gamma}_{m} = \hat{\omega}_{2,1,m} + \hat{\delta}_{2,1,m}^{o} -$

326 $(\hat{\omega}_{2,1,m}/\hat{\omega}_{2,2,m})(\hat{\omega}_{2,2,m} + \hat{\delta}_{2,2,m})$

327 **3.3.5 Panel Granger causality test**

328   In this section, we used Engel and Granger's multivariate panel-based Granger

329   causality test to test for Granger causality between variables[61]. Although it fails to

330   adequately address the endogeneity problem, the method can be effectively

331   implemented to examine the relationship between energy consumption and economic

332   growth in a multivariate setting, rather than a bivariate setting[62]. This method is

333   divided into two steps. The first step uses the OLS regression to estimate the residual

334   according to the long-term parameters, and the residual is used as the right variable.

335   The second step uses the right variable to estimate the short-term error correction

336   model. The Granger causality test formula is as Eq (15)- Eq (17):

$$\Delta TEC_{mn} = \gamma_{1m} + \sum_t \gamma_{11mt}\Delta TEC_{mn-t} + \sum_t \gamma_{12mt}\Delta GDP_{mn-t} + \sum_t \gamma_{13mt}\Delta X_{mn-t}$$
$$+ \alpha_{1m}ECT_{mn-1} + \beta_{1mn} \tag{15}$$

$$\Delta GDP_{mn} = \gamma_{2m} + \sum_t \gamma_{21mt}\Delta TEC_{mn-t} + \sum_t \gamma_{22mt}\Delta GDP_{mn-t} + \sum_t \gamma_{23mt}\Delta X$$
$$+ \alpha_{2m}ECT_{mn-1} + \beta_{2mn} \tag{16}$$

$$\Delta X_{mn} = \gamma_{3m} + \sum_t \gamma_{31mt}\Delta TEC_{mn-t} + \sum_t \gamma_{32mt}\Delta GDP_{mn-t} + \sum_t \gamma_{33mt}\Delta X_{mn-t}$$
$$+ \alpha_{3m}ECT_{mn-1} + \beta_{3mn} \tag{17}$$

337   Where ECT、t，Δ denotes the error correction term, hysteresis length and first-order

338   difference of the variable respectively. In this study, the Akaike information standard

339   is used to determine the optimal lag length.

340

341   **4. Empirical results**

342   **4.1 Results of cross-sectional dependency (CSD) tests**

343   Table A1 (in Appendix) shows the results of three cross-section dependence tests.

344   According to the parameters obtained from the results, we find that all variables reject

345   the null hypothesis at the 1% significance level, that is, reject the assumption of cross-

346   section independence. In other words, all variables of the panel model in this study

347   have cross-sectional dependence. For this phenomenon, we conduct a panel unit root

348   test.

349   **4.2 Unit root test results**

350   According to the results in Table 2, the unit root test results support those 7

351   variables have unit roots in the levels, that is, the levels are non-stationary. After the

352   first-order difference, all variables reject the null hypothesis, which means that all

353   variables are stable after the first-order difference. Therefore, it can be considered that

354   the variables selected in this study are first-order single-integration. This result

355   supports our next long-term cointegration test.

356   Table 2. Unit root test results

	Variables	LLC	IPS	ADF	PP-Fisher
	lnTEC	1.0367	8.1139	34.4291	29.645
	lnCOAL	4.4399	8.7338	18.9081	10.5975
	lnOIL	-3.2933***	0.6582	56.544	69.3393
I(0)	lnGAS	-0.7111	-0.5455	77.6073**	167.3300***
	lnGDP	3.1513	6.9294	27.0282	6.0355
	lnIS	-0.8201	0.3352	63.1201	46.8741
	lnOPEN	-2.1690**	4.0686	36.0776	21.3132
	lnTEC	-15.0904***	-12.7434***	229.5990***	307.2280***
	lnCOAL	-10.7739***	-9.7530***	198.1030***	244.9170***
	lnOIL	-16.4359***	-11.4821***	213.5880***	272.3120***
I(1)	lnGAS	-16.2636***	-14.0052***	254.0600***	307.4720***
	lnGDP	-7.7320***	-3.2984***	97.3505***	110.8540***
	lnIS	-6.6376***	-4.2402***	108.0870***	121.9480***
	lnOPEN	-18.1152***	-16.1038***	307.1690***	548.1210***

357   Note: ***, **, and * indicate that they can pass statistical tests with significance

358   levels of 1%, 5%, and 10%, respectively.

359   **4.2 Cointegration test results**

360   To further investigate whether there is a long-term cointegration relationship

361   between each group of variables, we adopted the Pedroni and Kao cointegration test.

362   The results of the cointegration test for each group are shown in Table A2 and Table

363   A3 (in Appendix). When exploring the impact of economic growth on the difference

364   of energy consumption based on energy sources, the selected three sub-energy sources

365   (coal, oil, and natural gas) are respectively used as the explained variables for

366   regression, so the cointegration test should also be performed separately. Similarly,

367   the high energy consumption region, middle energy consumption region and the low

368   energy consumption region are also tested for cointegration respectively. The Pedroni

369   cointegration test provides seven statistics, most of which show rejection of the null

370   hypothesis. The Kao test result also rejects the null hypothesis, so the results support a

371   cointegration relationship between variables. Each group of variables will be

372   cointegrated estimation in the next step.

373   **4.3 Regression estimation results**

374   According to the results of the cointegration test, there is a long-term

375   cointegration relationship between total energy consumption, coal consumption, oil

376   consumption, natural gas consumption and economic growth, industrial structure, and

377   trade openness. Therefore, it is allowed to continue to test the degree of cointegration

378   between variables through cointegration regression.

379

380

381 Table 3. Regression results of national economic growth and total energy consumption

Variable	OLS			FMOLS		
	Coefficient	T value	P value	Coefficient	T value	P value
lnGDP	0.5685***	21.8430	0.0000	0.6993***	12.9632	0.0000
lnIS	0.3701***	6.2476	0.0000	0.2162***	2.7655	0.0059
lnOPEN	0.0545***	3.0210	0.0026	0.0736***	5.4936	0.0000
C	4.4150***	33.0797	0.0000			

382 Note: ***, **, and * indicate that they can pass statistical tests with significance levels of 1%, 5%, and 10%, respectively.

383 Table 4. Regression results of economic growth and total energy consumption at the provincial level

Variable	High energy consumption region				Middle energy consumption region				Low energy consumption region			
	OLS		FMOLS		OLS		FMOLS		OLS		FMOLS	
	Statistics	P value	Statistics	P value	Statistics	P value	Statistics	P value	Statistics	P value	Statistics	P value
lnGDP	0.6621*** (14.8487)	0.0000	0.6193*** (21.6984)	0.0000	0.4393*** (9.1156)	0.0000	0.4216*** (15.0140)	0.0000	0.6061*** (14.2415)	0.0000	0.5815*** (5.8471)	0.0000
lnIS	0.5207*** (5.2096)	0.0000	0.4476*** (7.1600)	0.0000	0.1516* (1.8954)	0.0598	0.0865* (1.8204)	0.0706	0.6101*** (4.8308)	0.0000	0.5920*** (4.0789)	0.0001
lnOPEN	0.0039 (0.1327)	0.8946	0.0320* (1.7102)	0.0892	0.1602*** (4.8434)	0.0000	0.1732*** (8.8733)	0.0000	-0.0079 (-0.2485)	0.8040	0.0312 (1.2078)	0.2291

19

C	4.7974***	0.0000		3.6258***	0.0000		5.0388***	0.0000
	(25.1390)			(17.6447)			(17.2135)	

Note: ***, **, and * indicate that they can pass statistical tests with significance levels of 1%, 5%, and 10%, respectively.

Table 5. Regression results of economic growth and different sources of energy consumption

Variable	lnCOAL				lnOIL				lnGAS			
	OLS		FMOLS		OLS		FMOLS		OLS		FMOLS	
	Statistics	P value	Statistics	P value	Statistics	P value	Statistics	P value	Statistics	P value	Statistics	P value
lnGDP	0.47701***	0.0000	0.4736***	0.0000	0.1111	0.4841	1.5581***	0.0000	1.8362***	0.0000	0.8191***	0.0000
	(10.411)		(10.036)		(0.1124)		(33.2830)		(10.8222)		(16.6727)	
lnIS	0.8809***	0.0000	0.3883***	0.0000	0.6803*	0.0952	1.8463***	0.0000	0.5566	0.1644	2.4669***	0.0000
	(8.4346)		(7.0307)		(1.6716)		(32.3690)		(1.3926)		(42.2149)	
lnOPEN	0.0656***	0.0393	0.1802***	0.0062	0.5167***	0.0000	1.5453***	0.0000	-0.1339	0.2591	-0.5610***	0.0000
	(2.0662)		(2.7538)		(5.7609)		(22.3867)		(-1.1299)		(-8.3862)	
C	5.2339***	0.0000			-1.3105	0.1124			-8.1676***	0.0000		
	(22.2775)				(-1.5904)				(-9.3318)			

Note: ***, **, and * indicate that they can pass statistical tests with significance levels of 1%, 5%, and 10%, respectively.

387   This work examines the relationship between economic growth and energy

388   consumption from the perspective of energy sources and regional difference.

389   Industrial structure and trade openness are also included in the equation as control

390   variables. The results at the national level are shown in Table 3. The results of OLS

391   regression and FMOLS regression show that the directions of the elastic coefficients

392   of each variable are consistent, which proves that our results are robust. We focus on

393   explaining the results of the panel FMOLS. It is not difficult to find that economic

394   growth, industrial structure and regional openness are all significantly correlated with

395   the explained variables at the 1% statistical level. This implies that regional GDP,

396   industrial structure and trade openness have a close influence on total energy

397   consumption. Specifically, the regression coefficient of lnGDP is 0.6993, that is to say,

398   an increase in 1% of regional GDP can bring about a 0.6993% increase in energy

399   consumption, which shows that China's overall economic growth is still highly

400   dependent on energy consumption. The regression coefficient between the industrial

401   structure and the explained variable is 0.2162, which means that for every 1%

402   increase in the output value of the secondary industry in GDP, energy consumption

403   increases by 0.2162%. The secondary industry includes various industries and

404   manufacturing industries, and its development inevitably needs to consume a large

405   amount of fossil energy resources. Compared with the primary and tertiary industries,

406   the secondary industry is highly dependent on energy resources [63]. The regression

407   coefficient of trade openness is 0.0736, which means that the increase in trade

408   openness can promote energy consumption. The degree of regional openness is

409   positively correlated with total energy consumption. For China, the increase in total

410   imports and exports has a positive effect on energy consumption. Trade has many

411   ways of acting on energy consumption, including scale effect, structural effect, and

412 technology effect [64]. Among them, the scale effect increases energy consumption,

413 the technology effect reduces energy consumption, and the structure effect on energy

414 consumption depends on specific regional conditions [65]. Our results support that the

415 increase in the degree of regional openness in China's provinces promotes energy

416 consumption, which means that the sum of the technology and structural effects

417 brought about by trade cannot offset the scale effect. Finally, the regression

418 coefficient of lnGDP is much higher than that of lnIS (0.2162) and lnOPEN (0.0736).

419 Compared with industrial structure and regional openness, economic growth is the

420 main driving force for energy consumption.

421   At the inter-provincial level, the results are shown in Table 4. The total energy

422 consumption is selected as the dividing standard because existing studies have shown

423 that the relationship between economic growth and energy consumption has non-

424 linear characteristics [66, 67]. Comparing the results of the three groups, lnGDP and

425 lnTEC are both significantly correlated at a statistical level of 1%, which shows that

426 regardless of the level of total energy consumption, economic growth is closely

427 related to energy consumption growth. The difference is that the regression

428 coefficients of lnGDP in the three groups. Specifically, for the high energy

429 consumption region whose total energy consumption is higher than 190 million tons

430 of standard coal, economic growth has a promotion effect of 0.6193 on the total

431 energy consumption, which is the largest among the three groups; Next is the low

432 energy consumption region with total energy consumption less than 100 million tons

433 of standard coal. Economic growth has a promotion effect of 0.5815 on total energy

434 consumption; The promotion effect for the middle energy consumption region with

435 total energy consumption between 100 to 190 million tons of standard coal is 0.4216,

436 which is the weakest among the three groups. This result shows that the impact of

437 economic growth on energy consumption is heterogeneous in energy consumption

438 levels. The growth of energy consumption demand is more sensitive to economic

439 changes in provinces with higher energy consumption, followed by provinces with the

440 lowest energy consumption. The least sensitive are the provinces with medium energy

441 consumption.

442 **4.3 Granger causality test**

443 Table 6. Granger causality results of different types of energy consumption and

444 economic growth in China

Null Hypothesis:	F-Statistic	Prob.
lnGDP does not Granger Cause lnTEC	8.6550***	0.0002
lnTEC does not Granger Cause lnGDP	7.5463***	0.0006
lnOPEN does not Granger Cause lnTEC	2.5806*	0.0768
lnTEC does not Granger Cause lnOPEN	9.7175***	0.0001
lnIS does not Granger Cause lnTEC	6.4075***	0.0018
lnTEC does not Granger Cause lnIS	19.4557***	0.0000
lnGDP does not Granger Cause lnCOAL	24.1625***	0.0000
lnCOAL does not Granger Cause lnGDP	4.6238**	0.0103
lnOPEN does not Granger Cause lnCOAL	12.5296***	0.0000
lnCOAL does not Granger Cause lnOPEN	5.5953***	0.0040
lnIS does not Granger Cause lnCOAL	11.6859***	0.0000
lnCOAL does not Granger Cause lnIS	7.7984***	0.0005
lnGDP does not Granger Cause lnOIL	1.7229	0.1798
lnOIL does not Granger Cause lnGDP	0.7673	0.4649
lnOPEN does not Granger Cause lnOIL	2.0571	0.1291
lnOIL does not Granger Cause lnOPEN	1.6721	0.1891
lnIS does not Granger Cause lnOIL	0.2504	0.7786
lnOIL does not Granger Cause lnIS	3.5980**	0.0282
lnGDP does not Granger Cause lnGAS	6.9807***	0.0010
lnGAS does not Granger Cause lnGDP	12.4659***	0.0000
lnOPEN does not Granger Cause lnGAS	11.4698***	0.0000
lnGAS does not Granger Cause lnOPEN	2.8869*	0.0568
lnIS does not Granger Cause lnGAS	0.5877	0.5561
lnGAS does not Granger Cause lnIS	10.9694***	0.0000
lnOPEN does not Granger Cause lnGDP	2.8785*	0.0572
lnGDP does not Granger Cause lnOPEN	18.0967***	0.0000
lnIS does not Granger Cause lnGDP	1.9574	0.1424
lnGDP does not Granger Cause lnIS	21.0017***	0.0000
lnIS does not Granger Cause lnOPEN	10.6223***	0.0000

lnOPEN does not Granger Cause lnIS	13.9547***	0.0000

445   Note: ***, **, and * indicate that they can pass statistical tests with significance

446   levels of 1%, 5%, and 10%, respectively.

447   Table 7. Granger causality results of energy consumption and economic growth in

448   different regions

	High energy consumption region	Middle energy consumption region	Low energy consumption region
Null Hypothesis:	F-Statistic	F-Statistic	F-Statistic
lnGDP does not Granger Cause lnTEC	7.9765***	2.3111	3.5349**
lnTEC does not Granger Cause lnGDP	9.1872***	1.0809	0.4046
lnOPEN does not Granger Cause lnTEC	2.5188*	0.1395	1.5150
lnTEC does not Granger Cause lnOPEN	4.1131**	6.5622***	2.1680
lnIS does not Granger Cause lnTEC	1.9170	1.4601	2.1938
lnTEC does not Granger Cause lnIS	11.3852***	10.9663***	4.9932***
lnOPEN does not Granger Cause lnGDP	0.7841	6.1202***	1.4358
lnGDP does not Granger Cause lnOPEN	3.0494*	7.7562***	10.1951***
lnIS does not Granger Cause lnGDP	1.0063	0.4061	0.7839
lnGDP does not Granger Cause lnIS	9.0099***	10.5939***	8.1922***
lnIS does not Granger Cause lnOPEN	0.6602	5.9434***	5.5242***
lnOPEN does not Granger Cause lnIS	4.2876***	3.6509**	9.0304***

449   Note: ***, **, and * indicate that they can pass statistical tests with significance

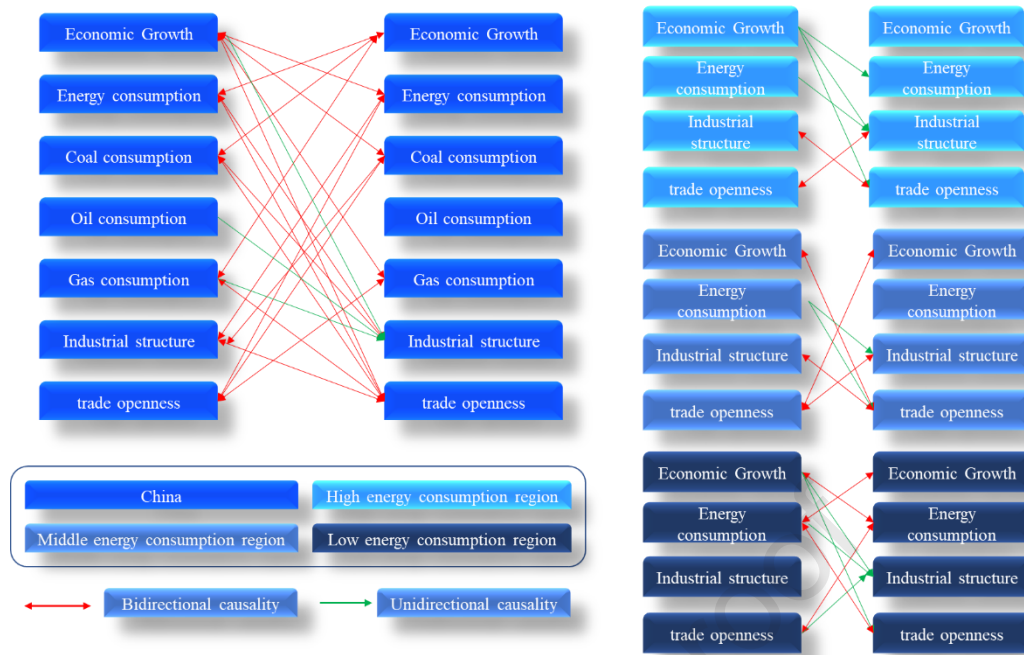450   levels of 1%, 5%, and 10%, respectively.

451

452

Figure 2. Schematic diagram of Granger causality test at national and regional

level.

Granger Causality testing can further help understand the interaction between variables. The test results focusing on energy sources and regional differences are shown in Table 6 and Table 7, respectively.

From Table 6 and Figure 2, bidirectional Granger causality from economic growth to energy consumption, coal consumption, and gas consumption was found at the national level. This validate the Feedback causality for the case of China. In addition, there is a bidirectional Granger causalities running from energy consumption, coal consumption to industrial structure. The industrial structure leads to the sources and changes of energy consumption. Moreover, bidirectional Granger causality also appears between energy consumption, coal consumption, gas consumption and trade openness. The results also indicate short-run unidirectional panel causality running from gas consumption and oil consumption toward industrial structure. Table 7 shows the results of Granger causality at the regional level. Among then, the Granger

468   causality is the most complex in the high energy consumption region, followed by the

469   low energy consumption region, and the simplest in the middle energy consumption

470   region. Specifically, high energy consumption region shows a bidirectional Granger

471   causality between economic growth and energy consumption. However, there is a

472   unidirectional Granger causality between economic growth and energy consumption

473   in low energy consumption region. Furthermore, energy consumption and trade

474   openness show a bidirectional Granger causality in high energy consumption region

475   and a unidirectional Granger causality in middle energy consumption region. Between

476   energy consumption and industrial structure, all regions show a unidirectional

477   Granger causality between energy consumption and industrial structure.

478

479   **5. Discussion of energy consumption of China's economic recovery of post-**

480   **Covid-19 pandemic**

481   **5.1 Insights from energy sources**

482   Among fossil energy sources, China economic recovery has the greatest driving

483   effect on oil consumption. For every 1% increase in regional GDP, the consumption

484   for oil increases by 1.5581%. Oil is the blood of industry and penetrates into all

485   aspects of the economy and society [68]. The expansion of the economic scale and the

486   improvement of the level of social activities have directly promoted the growth of oil

487   consumption [69]. Therefore, the oil market shows that oil consumption is highly

488   correlated with economic trends. During the financial crisis, the global economy fell

489   into recession, and oil demand grew negatively during the same period [70]; On the

490   contrary, the global economy grew during 2017-2019, and the demand for oil

491   increased during the same period [71]. As the world's largest industrial country,

492   China's economic development is dependent on oil consumption. In the early stage of

493   China's reform and opening up, limited by the level of science and technology,

494   China's pillar energy was coal [72]. However, with the rapid improvement of the

495   economic and technological level, the technology of oil extraction, transportation, and

496   refining has been improved [73, 74]. Combined with the advantages of higher oil

497   heating value and more convenient transportation, so that the rate of oil consumption

498   has continued to increase.

499   The 1% economic recovery has driven the demand for gas consumption to

500   increase by 0.8191%, second only to oil consumption. Actually, natural gas has

501   become an important transitional energy in the process of China's energy transition

502   due to its higher combustion efficiency and lower carbon emissions [75]. Over the

503   past two decades, China's natural gas market has been in short supply, with

504   consumption growth exceeding 10% in most years. Even in 2020, which is affected by

505   the epidemic, relatively rapid growth has been achieved. In the future, China's policy

506   of accelerating natural gas exploration and development will not change [76].

507   Therefore, in the context of China's rapid economic recovery in the post-epidemic era,

508   the demand for natural gas energy has also grown significantly.

509   Coal consumption is the least affected by economic growth. For every 1%

510   increase in GDP, the consumption of coal increases by 0.4736%. According to data

511   from the National Bureau of Statistics of China, as the world's largest coal consumer,

512   China's coal consumption has increased for the fourth consecutive year in 2020 [77].

513   In 2020, coal consumption accounted for 56.8% of total energy consumption, a

514   decrease of 0.9 percentage points from the previous year. Under the direction of green

515   development and low-carbon development of China's energy revolution, relevant

516   departments in various regions are also promoting continuous innovation in the coal

517   industry [78]. In recent years, the proportion of coal in energy consumption has

518   continued to decline in China. This may be the reason why the elasticity coefficient of

519   coal energy and the economy is smaller than that of oil and natural gas. However, due

520   to the large amount of coal resources in China and the relatively large proportion of

521   thermal power generation, coal still holds a strong position as the main energy source.

522   Therefore, coal consumption still has a significant positive correlation with China's

523   economic growth.

524   **5.2 Insights from regional different**

525   Figure 3 illustrates the spatial distribution of the relationship between energy

526   consumption and economic growth in China 30 provinces. For high energy

527   consumption region, energy consumption has increased the most. High energy

528   consumption region includes Shandong, Guangdong, Jiangsu, Hebei, Henan, Liaoning,

529   Zhejiang, Sichuan, Shanxi, and Inner Mongolia. Among them, Jiangsu and Zhejiang

530   belong to the Yangtze River Delta region of China. As China's economic center, the

531   terminal energy consumption is the largest, but it is energy-scarce areas. Due to the

532   high dependence on inputs from outside, energy supply is facing tremendous pressure.

533   Guangdong Province belongs to the Pearl River Delta region and is the frontier of

534   China's reform and opening up. Like the Yangtze River Delta region, the Pearl River

535   Delta region is an energy importing region [79]. However, Liaoning and Shanxi used

536   to be China's important industrial and energy supply bases and typical energy output

537   regions, with huge coal production [80]. During the recovery period of China's

538   economy, as the region where energy consumption is most affected by economic

539   growth, high energy consumption region first faced huge energy consumption demand.

540   Zhejiang, Inner Mongolia, and Guangdong all implemented power curtailment

541   policies. For low energy consumption region, Beijing has entered a post-industrial

542   development stage, and Tianjin has basically completed industrialization. The rapid

543   development of social economy has brought about a continuous increase in the total

544   energy consumption [81], which has intensified the degree of external dependence on

545   regional energy supply. The overall situation of energy shortage is present. In addition,

546   Ningxia and Chongqing are important bases for China's "West-to-East coal

547   transportation", "West-to-East gas transmission" and "West-to-East power

548   transmission", and are important cornerstones for ensuring energy security [82]. The

549   energy consumption brought about by economic growth in the eastern region has

550   finally been implemented in these resource-based provinces. Therefore, in the context

551   of rapid economic growth, the energy consumption of the low energy consumption

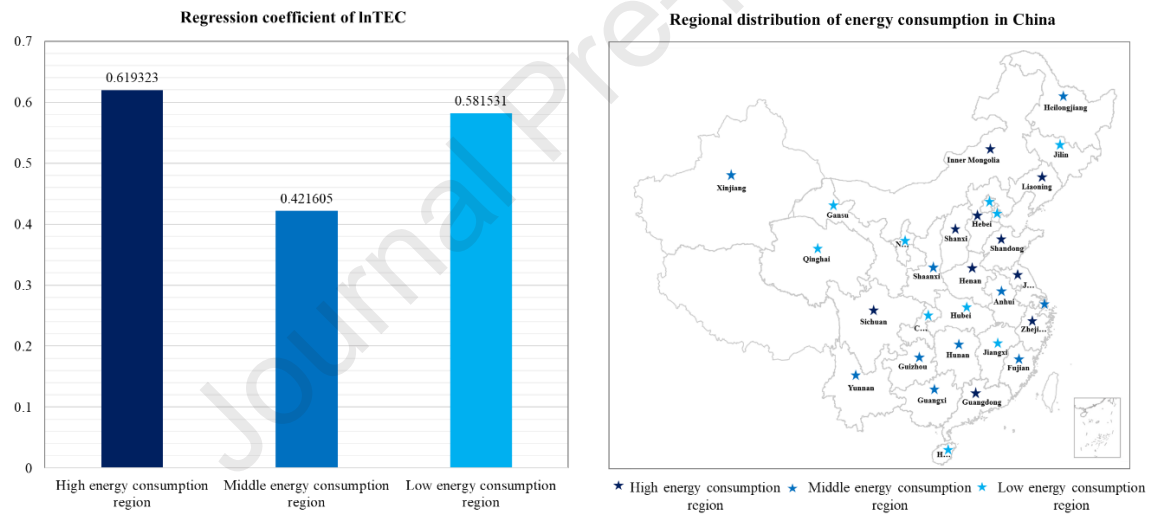552   region is second only to the high energy consumption region.

553

554   Figure 3. The geographical distribution of the relationship between economic

555   growth and total energy consumption in China 30 provinces.

556

557   **6 Conclusions and policy implications**

558   This study uses the data of 30 provinces in China from 2000 to 2017 to analyze

559   the relationship between economic growth and energy consumption through the

560   energy consumption functions. The conclusions are as follows: First, the total energy

561 consumption is positively affected by economic growth, industrial structure, and trade

562 openness. Economic growth has the greatest impact on total energy consumption,

563 which is 0.6993. Second, for various fossil energy, the consumption of oil is most

564 driven by economic growth, at 1.5581, followed by natural gas consumption at 0.8191

565 and coal consumption at 0.4736. Third, the relationship between energy consumption

566 and economic growth in each province has regional difference. The promotion of

567 economic growth on energy consumption is strongest in provinces with high energy

568 consumption, followed by provinces with low energy consumption, and the weakest

569 in provinces with middle energy consumption.

570   An energy security reserve system must be established to ensure the security of

571 energy supply in the post-Covid-19 pandemic and four measures can be taken. First,

572 the scale of strategic oil reserves needs to be expanded. The conclusion shows that

573 China's economic recovery after COVID-19 increases oil consumption demand

574 dramatically. However, China's domestic oil supply cannot meet the demand and the

575 current dependence on foreign oil exceeds 70%. To prevent the scale of strategic oil

576 reserves from being unable to meet the needs of national strategic security, the

577 Chinese government may consider expanding the scale of strategic oil reserves by

578 taking advantage of the short-term oil price situation. Second, the rupture of the

579 natural gas industry chain must be avoided and relevant measures must be

580 implemented to make the natural gas market stable and guide the development of the

581 industry. Third, the National Energy Administration and coal production enterprises

582 need to work together to ensure a stable supply of coal. As China's basic energy

583 source, a stable supply of coal must be ensured. In the early days of the epidemic, the

584 failure of production recovery resulted in a tight coal supply side. The imbalance

585 between supply and demand in the coal market will continue in the short term. Under

586   this condition, the National Energy Administration should strengthen the information

587   communication between coal transfer places and improve the tripartite connection

588   among production, transportation and demand to ensure that the national thermal coal

589   reserve is at a reasonable level. At the meantime, coal production enterprises should

590   adhere to scientific production and sales, maintain the stability of coal market prices

591   and standardize the use of coal price indices. Finally, the transformation of energy

592   consumption structure is preferred. When laying out a new round of energy security

593   strategies, the transition of clean energy should be considered to make balance

594   between energy security and environmental protection. Based on the experience of

595   developed countries during the two oil crises in 1973 and 1979, the government can

596   take the opportunity to promote the transformation of energy consumption structure

597   through regulations and policies such as fuel taxes.

598   The energy policy must consider local conditions due to the regional differences

599   in increased energy consumption with economic growth. Because of the huge energy

600   demand in Yangtze River Delta region, an energy institution in the Yangtze River

601   Delta region can be established to optimize energy plans. For Guangzhou with high

602   degree of opening to the outside world, the main body of energy consumption can be

603   transited to clean energy through the establishment of clean energy production,

604   storage and transportation infrastructure. For the old industrial districts such as Shanxi,

605   Jilin, Heilongjiang, Liaoning and energy-rich regions such as Xinjiang, Ningxia, and

606   Inner Mongolia, the energy resource potential must be fully utilized to guarantee the

607   national energy security supply. With the large regional differences shown above,

608   both the regional resource potential and the status quo of energy system should be

609   considered to promote the cross-regional energy cooperation.

610   Further research can be carried out from the following aspects. Firstly, a

611   forecasting model can be added if further quarterly data is available. The regional

612   economic growth rate in the late stage of COVID-19 can be obtained through the

613   prediction model, and then combined with the cointegration model in this study, the

614   prediction of future energy consumption can be achieved[83]. Secondly, with the

615   change of China's energy structure, the status of renewable energy cannot be ignored.

616   Therefore, renewable energy can be further included in the energy consumption

617   function if renewable energy consumption data can be obtained. Third, categorizing

618   regions based on energy consumption levels alone does not fully address the issue of

619   heterogeneity. Further exploration of heterogeneity based on the structural fracture

620   hypothesis can be performed if nonlinear panel regression techniques can be

621   employed.

622

623 **Appendix A**

624 Table A1. Cross-sectional dependence tests results.

Cross-sectional dependence test	Breusch-Pagan LM test		Pesaran scaled LM test		Pesaran CD test	
Variables	Statistic	P-value	Statistic	P-value	Statistic	P-value
lnTEC	7237.5170***	0.0000	230.6269***	0.0000	84.8822***	0.0000
lnCOAL	5900.9630***	0.0000	185.3135***	0.0000	69.8754***	0.0000
lnOIL	3209.7940***	0.0000	94.0743***	0.0000	45.5230***	0.0000
lnGAS	4718.0620***	0.0000	145.2094***	0.0000	65.4208***	0.0000
lnGDP	7714.1750***	0.0000	246.7871***	0.0000	87.8274***	0.0000
lnIS	3313.2940***	0.0000	97.5833***	0.0000	43.7949***	0.0000
lnOPEN	6882.3860***	0.0000	218.5869***	0.0000	82.7390***	0.0000

625 Note: ***, **, and * indicate that they can pass statistical tests with significance

626 levels of 1%, 5%, and 10%, respectively.

627 Table A2. Cointegration test results of different types of energy consumption and

628 economic growth

Explained variable	Total energy consumption		Coal consumption		Oil consumption		Natural gas consumption	
Pedroni Cointegration Test	Statistics	P value	Statistics	P value	Statistics	P value	Statistics	P value
Panel v-Statistic	40.5625***	0.0000	-1.0336	0.8493	1.9030**	0.0285	0.5022	0.3078
Panel rho-statistic	3.7157	0.9999	2.8536	0.9978	0.4664	0.6795	0.4260	0.6650
Panel PP-statistic	0.4090	0.6587	-4.3305***	0.0000	-3.5265***	0.0002	-4.2808***	0.0000
Panel ADF-statistic	-2.3217**	0.0101	-4.2924***	0.0000	-4.5770***	0.0000	-4.5338***	0.0000
Group rho-statistic	5.0084	1.0000	4.8608	1.0000	2.2374	0.9874	2.4359	0.9926
Group PP-statistic	-3.1322***	0.0009	-4.1215***	0.0000	-6.3236***	0.0000	-8.5190***	0.0000
Group ADF-Statistic	-2.6831***	0.0036	-5.5972***	0.0000	-6.7703***	0.0000	-7.5637***	0.0000
Kao Cointegration Test	Statistics	P value	Statistics	P value	Statistics	P value	Statistics	P value
ADF	-3.2910***	0.0005	1.7327*	0.0416	-4.8174***	0.0000	-5.4623***	0.0000
Residual variance	0.0055		0.0095		0.0086		0.0078	

| HAC variance | 0.0078 | 0.0140 | 0.0130 | 0.0114 |

629 Note: ***, **, and * indicate that they can pass statistical tests with significance

630 levels of 1%, 5%, and 10%, respectively.

631 Table A3. Inter-provincial cointegration test results between total energy consumption

632 and economic growth

Region	High energy consumption region		Middle energy consumption region		Low energy consumption region	
Pedroni Cointegration Test	Statistics	P value	Statistics	P value	Statistics	P value
Panel v-Statistic	-0.6375	0.7381	10.9828***	0.0000	5.9558***	0.0000
Panel rho-statistic	0.9602	0.8315	1.2958***	0.9025	-0.0436	0.4826
Panel PP-statistic	-1.8800**	0.0301	-2.6417***	0.0041	-7.2421***	0.0000
Panel ADF-statistic	-2.7421***	0.0031	-3.0420	0.0012	-8.9448***	0.0000
Group rho-statistic	1.8353	0.9668	2.3201	0.9898	1.5464	0.9390
Group PP-statistic	-3.8153***	0.0001	-5.0638***	0.0000	-9.8837***	0.0000
Group ADF-Statistic	-3.6534***	0.0001	-4.7324***	0.0000	-8.2984***	0.0000
Kao Cointegration Test	Statistics	P value	Statistics	P value	Statistics	P value
ADF	-5.5238***	0.0000	1.9781**	0.0240	-1.4868*	0.0685
Residual variance	0.0034		0.0015		0.0014	
HAC variance	0.0039		0.0025		0.0020	

633 Note: ***, **, and * indicate that they can pass statistical tests with significance

634 levels of 1%, 5%, and 10%, respectively.

635

636

637

638

References

[1] A. Atkeson, What Will Be the Economic Impact of Covid-19 in the Us? Rough Estimates of Disease Scenarios, Labor: Demographics & Economics of the Family eJournal, (2020).

[2] Y. Qiu, X. Chen, W. Shi, Impacts of Social and Economic Factors on the Transmission of Coronavirus Disease 2019 (COVID-19) in China, medRxiv, (2020).

[3] Q. Wang, M. Su, M. Zhang, R. Li, Integrating Digital Technologies and Public Health to Fight Covid-19 Pandemic: Key Technologies, Applications, Challenges and Outlook of Digital Healthcare, International Journal of Environmental Research and Public Health, 18 (2021).

[4] V. Alfano, S. Ercolano, The Efficacy of Lockdown Against COVID-19: A Cross-Country Panel Analysis, Applied Health Economics and Health Policy, 18 (2020) 509-517.

[5] Q. Wang, R. Huang, The impact of COVID-19 pandemic on sustainable development goals – A survey, Environmental Research, 202 (2021) 111637.

[6] G. Feng, H. Yang, Q. Gong, C.-p. Chang, What is the exchange rate volatility response to COVID-19 and government interventions?, Economic Analysis and Policy, 69 (2021) 705-719.

[7] N. Fernandes, Economic Effects of Coronavirus Outbreak (COVID-19) on the World Economy, IESE Business School Working Paper Series, (2020).

[8] P.F. Rupani, M. Nilashi, R.A. Abumalloh, S. Asadi, S.A. Samad, S. Wang, Coronavirus pandemic (COVID-19) and its natural environmental impacts, International Journal of Environmental Science and Technology, (2020) 1 - 12.

[9] W. Strielkowski, I. Firsova, I. Lukashenko, J. Raudeliūnienė, M. Tvaronavičienė, Effective Management of Energy Consumption during the COVID-19 Pandemic: The Role of ICT Solutions, Energies, 14 (2021) 893.

671   [10] P. Narayan, Oil price news and COVID-1Y Is there any connection?, 2020.

672   [11] K. Prabheesh, R. Padhan, B. Garg, COVID-19 and the Oil Price@ Stock Market

673   Nexus: Evidence From Net Oil-Importing Countries, 2020.

674   [12] Q. Wang, S. Li, R. Li, F. Jiang, Underestimated impact of the COVID-19 on

675   carbon emission reduction in developing countries – A novel assessment based on

676   scenario analysis, Environmental Research, 204 (2022) 111990.

677   [13] T.s.c.i. office, China's energy consumption sees rapid H1 growth: Official, 2021.

678   [14] H. Zhu, L. Duan, Y. Guo, K. Yu, The effects of FDI, economic growth and

679   energy consumption on carbon emissions in ASEAN-5: Evidence from panel quantile

680   regression, Economic Modelling, 58 (2016) 237-248.

681   [15] B. Saboori, J. Sulaiman, Environmental degradation, economic growth and

682   energy consumption: Evidence of the environmental Kuznets curve in Malaysia,

683   Energy Policy, 60 (2013) 892-905.

684   [16] Q. Wang, F. Zhang, What does the China's economic recovery after COVID-19

685   pandemic mean for the economic growth and energy consumption of other countries?,

686   Journal of Cleaner Production, 295 (2021) 126265.

687   [17] M.-W. Deng, W. Li, Y. Hu, Decomposing Industrial Energy-Related CO 2

688   Emissions in Yunnan Province, China: Switching to Low-Carbon Economic Growth,

689   Energies, 9 (2016) 23.

690   [18] S.S. Akadiri, A.A. Alola, O. Usman, Energy mix outlook and the EKC

691   hypothesis in BRICS countries: a perspective of economic freedom vs. economic

692   growth, Environmental Science and Pollution Research, 28 (2021) 8922-8926.

693   [19] K. Saidi, S. Hammami, The impact of energy consumption and CO2 emissions

694   on economic growth: Fresh evidence from dynamic simultaneous-equations models,

695   Sustainable Cities and Society, 14 (2015) 178-186.

696   [20] U. Soytas, R. Sari, Energy consumption and GDP: causality relationship in G-7

697   countries and emerging markets, Energy Economics, 25 (2003) 33-37.

698   [21] B. Doğan, D. Balsalobre-Lorente, M.A. Nasir, European commitment to COP21

699   and the role of energy consumption, FDI, trade and economic complexity in

700   sustaining economic growth, Journal of Environmental Management, 273 (2020)

701   111146.

702   [22] E. Yu, B.-K. Hwang, The relationship between energy and GNP: Further results,

703   Energy Economics, 6 (1984) 186-190.

704   [23] A. Akarca, T.V. Long, Energy and employment: a time-series analysis of the

705 causal relationship, Resources and Energy, 2 (1979) 151-162.

706 [24] F. Fallahi, Causal relationship between energy consumption (EC) and GDP: A

707 Markov-switching (MS) causality, Energy, 36 (2011) 4165-4170.

708 [25] S. Nasreen, S. Anwar, Causal relationship between trade openness, economic

709 growth and energy consumption: A panel data analysis of Asian countries, Energy

710 Policy, 69 (2014) 82-91.

711 [26] N. Bowden, J.E. Payne, The causal relationship between U.S. energy

712 consumption and real output: A disaggregated analysis, Journal of Policy Modeling,

713 31 (2009) 180-188.

714 [27] N.S. Bowden, J.E. Payne, Sectoral Analysis of the Causal Relationship Between

715 Renewable and Non-Renewable Energy Consumption and Real Output in the US,

716 Energy Sources, Part B: Economics, Planning, and Policy, 5 (2010) 400 - 408.

717 [28] U. Soytas, R. Sari, B.T. Ewing, Energy consumption, income, and carbon

718 emissions in the United States, Ecological Economics, 62 (2007) 482-489.

719 [29] I. Ozturk, A literature survey on energy–growth nexus, Energy Policy, 38 (2010)

720 340-349.

721 [30] G. Altinay, E. Karagol, Structural break, unit root, and the causality between

722 energy consumption and GDP in Turkey, Energy Economics, 26 (2004) 985-994.

723 [31] S. Paul, R.N. Bhattacharya, Causality between energy consumption and

724 economic growth in India: a note on conflicting results, Energy Economics, 26 (2004)

725 977-983.

726 [32] F. Halicioglu, An econometric study of CO2 emissions, energy consumption,

727 income and foreign trade in Turkey, Energy Policy, 37 (2009) 1156-1164.

728 [33] F. Emirmahmutoglu, Z. Denaux, M. Topcu, Time-varying causality between

729 renewable and non-renewable energy consumption and real output: Sectoral evidence

730 from the United States, Renewable and Sustainable Energy Reviews, 149 (2021)

731 111326.

732 [34] F. Ge, B. Ye, S. Xing, B. Wang, S. Sun, The analysis of the underlying reasons

733 of the inconsistent relationship between economic growth and the consumption of

734 electricity in China – A case study of Anhui province, Energy, 128 (2017) 601-608.

735 [35] X. Liu, Z. Wang, X. Sun, L. Zhang, M. Zhang, Clarifying the relationship among

736 clean energy consumption, haze pollution and economic growth–based on the

737 empirical analysis of China's Yangtze River Delta Region, Ecological Complexity, 44

738 (2020) 100871.

[36] P. Sadorsky, Renewable energy consumption and income in emerging economies, Energy Policy, 37 (2009) 4021-4028.

[37] A.N. Menegaki, Growth and renewable energy in Europe: A random effect model with evidence for neutrality hypothesis, Energy Economics, 33 (2011) 257-263.

[38] C.-C. Lee, The causality relationship between energy consumption and GDP in G-11 countries revisited, Energy Policy, 34 (2006) 1086-1093.

[39] N. Apergis, J.E. Payne, CO2 emissions, energy usage, and output in Central America, Energy Policy, 37 (2009) 3282-3286.

[40] Y. Hao, L.-O. Wang, C.-C. Lee, Financial development, energy consumption and China's economic growth: New evidence from provincial panel data, International Review of Economics & Finance, 69 (2020) 1132-1151.

[41] M. Saldivia, W. Kristjanpoller, J.E. Olson, Energy consumption and GDP revisited: A new panel data approach with wavelet decomposition, Applied Energy, 272 (2020) 115207.

[42] M. Bhattacharya, S. Rafiq, S. Bhattacharya, The role of technology on the dynamics of coal consumption–economic growth: New evidence from China, Applied Energy, 154 (2015) 686-695.

[43] R. Li, G.C.K. Leung, Coal consumption and economic growth in China, Energy Policy, 40 (2012) 438-443.

[44] M.E. Bildirici, T. Bakirtas, The relationship among oil, natural gas and coal consumption and economic growth in BRICTS (Brazil, Russian, India, China, Turkey and South Africa) countries, Energy, 65 (2014) 134-144.

[45] T. Jin, J.-S. Kim, Coal Consumption and Economic Growth: Panel Cointegration and Causality Evidence from OECD and Non-OECD Countries, Sustainability, 10 (2018) 660.

[46] Q. Wang, S. Li, M. Zhang, R. Li, Impact of COVID-19 pandemic on oil consumption in the United States: A new estimation approach, Energy, 239 (2022) 122280.

[47] Y. Zheng, D. Luo, Industrial structure and oil consumption growth path of China: Empirical evidence, Energy, 57 (2013) 336-343.

[48] G. Zou, K.W. Chau, Short- and long-run effects between oil consumption and economic growth in China, Energy Policy, 34 (2006) 3644-3655.

[49] H. Naser, Analysing the long-run relationship among oil market, nuclear energy consumption, and economic growth: An evidence from emerging economies, Energy,

89 (2015) 421-434.

[50] Z.-G. Li, H. Cheng, T.-Y. Gu, Research on dynamic relationship between natural gas consumption and economic growth in China, Structural Change and Economic Dynamics, 49 (2019) 334-339.

[51] C. Magazzino, M. Mele, N. Schneider, A D2C algorithm on the natural gas consumption and economic growth: Challenges faced by Germany and Japan, Energy, 219 (2021) 119586.

[52] T. Breusch, A. Pagan, The Lagrange Multiplier Test and its Applications to Model Specification in Econometrics, The Review of Economic Studies, 47 (1980) 239-253.

[53] B.H. Baltagi, Q. Feng, C. Kao, A Lagrange Multiplier test for cross-sectional dependence in a fixed effects panel data model, Journal of Econometrics, 170 (2012) 164-177.

[54] A. Levin, C.-F. Lin, C.-S.J. Chu, Unit root tests in panel data: asymptotic and finite-sample properties, Journal of econometrics, 108 (2002) 1-24.

[55] K.S. Im, M.H. Pesaran, Y. Shin, Testing for unit roots in heterogeneous panels, Journal of econometrics, 115 (2003) 53-74.

[56] P.C. Phillips, P. Perron, Testing for a unit root in time series regression, Biometrika, 75 (1988) 335-346.

[57] P. Pedroni, Fully modified OLS for heterogeneous cointegrated panels, Nonstationary panels, panel cointegration, and dynamic panels, Emerald Group Publishing Limited2001, pp. 93-130.

[58] C. Kao, Spurious regression and residual-based tests for cointegration in panel data, Journal of econometrics, 90 (1999) 1-44.

[59] C. Liu, Y. Jiang, R. Xie, Does income inequality facilitate carbon emission reduction in the US?, Journal of Cleaner Production, 217 (2019) 380-387.

[60] P. Pedroni, Fully modified OLS for heterogeneous cointegrated panels, Advances in econometrics, 15 (2000) 93-130.

[61] R.F. Engle, C.W. Granger, Co-integration and error correction: representation, estimation, and testing, Econometrica: journal of the Econometric Society, (1987) 251-276.

[62] M. Shahbaz, M. Zeshan, T. Afza, Is energy consumption effective to spur economic growth in Pakistan? New evidence from bounds test to level relationships and Granger causality tests, Economic Modelling, 29 (2012) 2310-2319.

807 [63] J.-D. Wurlod, J. Noailly, The impact of green innovation on energy intensity: An

808 empirical analysis for 14 industrial sectors in OECD countries, Energy Economics, 71

809 (2018) 47-61.

810 [64] R. Li, Q. Wang, Y. Liu, R. Jiang, Per-capita carbon emissions in 147 countries:

811 The effect of economic, energy, social, and trade structural changes, Sustainable

812 Production and Consumption, 27 (2021) 1149-1164.

813 [65] L.-S. Lau, C.-K. Choong, Y.-K. Eng, Investigation of the environmental Kuznets

814 curve for carbon emissions in Malaysia: Do foreign direct investment and trade

815 matter?, Energy Policy, 68 (2014) 490-497.

816 [66] M. Shahbaz, Q.M.A. Hye, A.K. Tiwari, N.C. Leitão, Economic growth, energy

817 consumption, financial development, international trade and CO2 emissions in

818 Indonesia, Renewable and Sustainable Energy Reviews, 25 (2013) 109-121.

819 [67] M. PjBatowska, A. XBodarczyk, Decoupling Economic Growth From Carbon

820 Dioxide Emissions in the EU Countries, Montenegrin journal of economics, 14 (2018)

821 7-26.

822 [68] I.A. Mensah, M. Sun, C. Gao, A.Y. Omari-Sasu, D. Zhu, B.C. Ampimah, A.

823 Quarcoo, Analysis on the nexus of economic growth, fossil fuel energy consumption,

824 CO2 emissions and oil price in Africa based on a PMG panel ARDL approach,

825 Journal of Cleaner Production, 228 (2019) 161-174.

826 [69] J.B. Ang, Economic development, pollutant emissions and energy consumption

827 in Malaysia, Journal of Policy Modeling, 30 (2008) 271-278.

828 [70] G.E. Halkos, E.-C. Gkampoura, Evaluating the effect of economic crisis on

829 energy poverty in Europe, Renewable and Sustainable Energy Reviews, 144 (2021)

830 110981.

831 [71] A. Dagoumas, F. Kitsios, Assessing the impact of the economic crisis on energy

832 poverty in Greece, Sustainable Cities and Society, 13 (2014) 267-278.

833 [72] B. Xu, B. Lin, Investigating drivers of CO2 emission in China's heavy industry:

834 A quantile regression analysis, Energy, 206 (2020) 118159.

835 [73] R. Dubey, A. Gunasekaran, S.J. Childe, T. Papadopoulos, Z. Luo, S.F. Wamba,

836 D. Roubaud, Can big data and predictive analytics improve social and environmental

837 sustainability?, Technological Forecasting and Social Change, 144 (2019) 534-545.

838 [74] J. Chen, M. Gao, S.K. Mangla, M. Song, J. Wen, Effects of technological

839 changes on China's carbon emissions, Technological Forecasting and Social Change,

840 153 (2020) 119938.

841 [75] K. Dong, R. Sun, G. Hochman, X. Zeng, H. Li, H. Jiang, Impact of natural gas

842 consumption on CO2 emissions: Panel data evidence from China's provinces, Journal

843 of Cleaner Production, 162 (2017) 400-410.

844 [76] H. Li, M. Shahbaz, H. Jiang, K. Dong, Is Natural Gas Consumption Mitigating

845 Air Pollution? Fresh Evidence from National and Regional Analysis in China,

846 Sustainable Production and Consumption, 27 (2021) 325-336.

847 [77] bp, BP Statistical Review of World, 2021.

848 [78] S. Xu, The paradox of the energy revolution in China: A socio-technical

849 transition perspective, Renewable and Sustainable Energy Reviews, 137 (2021)

850 110469.

851 [79] J. Wang, S. Wang, S. Li, K. Feng, Coupling analysis of urbanization and energy-

852 environment efficiency: Evidence from Guangdong province, Applied Energy, 254

853 (2019) 113650.

854 [80] Z. Li, H. Dai, L. Sun, Y. Xie, Z. Liu, P. Wang, H. Yabar, Exploring the impacts

855 of regional unbalanced carbon tax on CO2 emissions and industrial competitiveness in

856 Liaoning province of China, Energy Policy, 113 (2018) 9-19.

857 [81] U. Soytas, R. Sari, Energy consumption, economic growth, and carbon emissions:

858 Challenges faced by an EU candidate member, Ecological Economics, 68 (2009)

859 1667-1675.

860 [82] Z. Ling, T. Huang, J. Li, S. Zhou, L. Lian, J. Wang, Y. Zhao, X. Mao, H. Gao, J.

861 Ma, Sulfur dioxide pollution and energy justice in Northwestern China embodied in

862 West-East Energy Transmission of China, Applied Energy, 238 (2019) 547-560.

863 [83] Q. Wang, S. Li, F. Jiang, Uncovering the impact of the COVID-19 pandemic on

864 energy consumption: New insight from difference between pandemic-free scenario

865 and actual electricity consumption in China, Journal of Cleaner Production, 313 (2021)

866 127897.

867

868

Highlight

✧ Multiple linear regression panels and data from 30 provinces in China from 2000 to 2017 were used.

✧ China's economic growth has the largest increase in oil consumption, and the smallest increase in coal consumption.

✧ The energy consumption of provinces with different energy consumption levels is affected differently by China's economic recovery.

✧ Energy consumption growth in high-energy-consuming provinces is most affected by economic growth.

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: